NA49/NA61 vs FLUKA

Wrap-up and final results for NOνA Collaboration meeting

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What's new

- Full wrap-up.
- New NA49 data points taken into account.
- New results for K^+ and K^+/π^+ ratio in NA61.
- Now both NA49 and NA61 are completely covered.
- Results are available in accessible .txt and .root formats.

NA49

Quick reminder

Beam: Protons with 158 GeV momentum

Target: Graphite for the **pion** production analysis and hydrogen for **kaon** analysis.

FLUKA: Version 2011.2b.4.

We're measuring invariant cross section binned in CMS Feynman X and transverse momentum (x_F, p_T).

$$f(x_F, p_T) = E(x_F, p_T)\frac{d^3\sigma}{dp^3}$$

NA61

Changes w.r.t. NA49

Beam: Protons, now with 31GeV momentum instead of 158 GeV.

Target: Graphite.

FLUKA: Again, version 2011.2b.4.

Now we measure differential cross-section binned in total momentum and polar angle, both in LAB frame.

$$f(p,\theta) = \frac{d\sigma}{dp}$$

General procedure

- Run FLUKA simulation. For this presentation, 25×10^9 POT in each case.
  - 500 statistically independent runs of 5×10^7 POT each.
  - **Note:** Error is computed as the variance of these 500 estimators.
- Gather the results and compute errors using pyROOT.
- Read NA49/NA61 data and compare to FLUKA using pyROOT. Build desired plots/histograms.

Some details

USRYIELD FLUKA function :

- It can calculate invariant cross section in (x_F, p_T). By default uses the nucleon-nucleon CMS and gives the result in mb/GeV^2 (same as NA49).
- It can also calculate double differential cross sections $(\frac{\partial^2\sigma}{\partial\theta\partial p})$ binned in (θ, p) in the LAB frame.
- Scores particles as they emerge from the collision. Thus we avoid issues with reinteraction and decays.

Physics

- One run with FLUKA default PEANUT setting (using PEANUT for energy < 5 GeV).
- Another run forcing PEANUT for all interactions (as used in G4NUMI).

Some details

Binning

- NA49 includes finite bin size correction factor. We can pick thin bins (0.005 wide in both x_F and p_T) so that correction is negligible.
- NA61 do **not** include finite bin size correction factor. Thus we must match exactly the bins in NA61.

Normalization

- For NA61 we multiply the results by the width of the θ bin to get one-differential cross section $\frac{\partial \sigma}{\partial p}$ (same as NA61).
- In the case of NA49 no width factor is applied to the invariant cross section.
- We scale all results by the interaction probability.

Aside: Interaction probability

- The cross-sections given by FLUKA represent the probability that a given proton collides and produces a certain particle.
- The cross-sections in NA49/61 represent the probability that a certain collision produces a certain particle.
- To get the same quantity, we scale by the interaction length.

$$L_{int} = \frac{A}{\sigma \rho N_A}$$

$$p_{int} = 1 - e^{\frac{L}{L_{int}}}$$

Some details

Comparison

- Standardized differences:

$$z = \frac{f_{FLUKA} - f_{NA}}{\sqrt{\sigma^2_{FLUKA} + \sigma^2_{NA}}}$$

- Relative differences:

$$z = 100 \frac{f_{FLUKA} - f_{NA}}{f_{NA}}$$

Weights
Outline

1. Grab a flux file
2. Plot pt:pz distribution of neutrino parents in CC QE events.
3. Interpolate to estimate the values at NA49 bin centres.
4. Use those as weights for FLUKA - NA49/NA61 statistics.

Note: These weights correspond to events in the NDOS detector. The procedure can be easily generalized for other weight distributions.

Weights
Outline

Weights are computed selecting the following decay channels.

π^+: $\pi^+ \to \nu_\mu + \mu^+$

π^-: $\pi^- \to \bar{\nu}_\mu + \mu^-$

K^+: $K^+ \to \nu_\mu + \mu^+$

$K^+ \to \nu_\mu + \pi^0 + \mu^+$

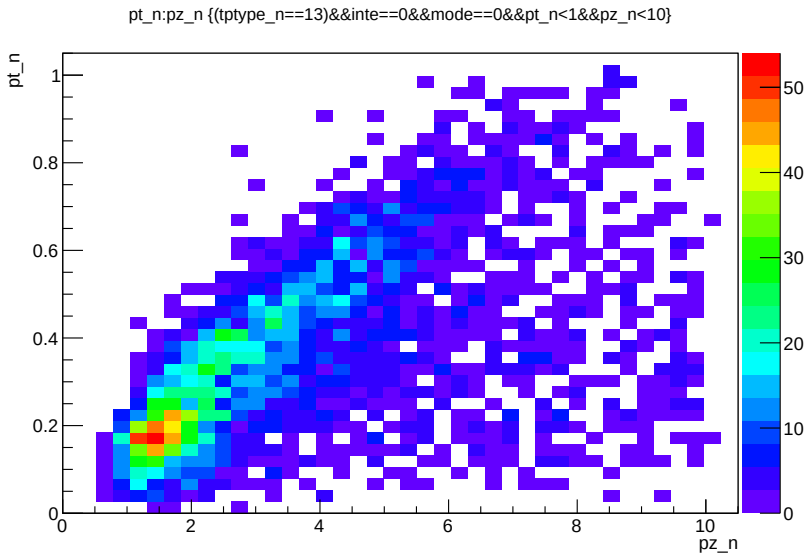
$K^+ \to \nu_e + \pi^0 + e^+$

K^-: $K^- \to \bar{\nu}_\mu + \mu^-$

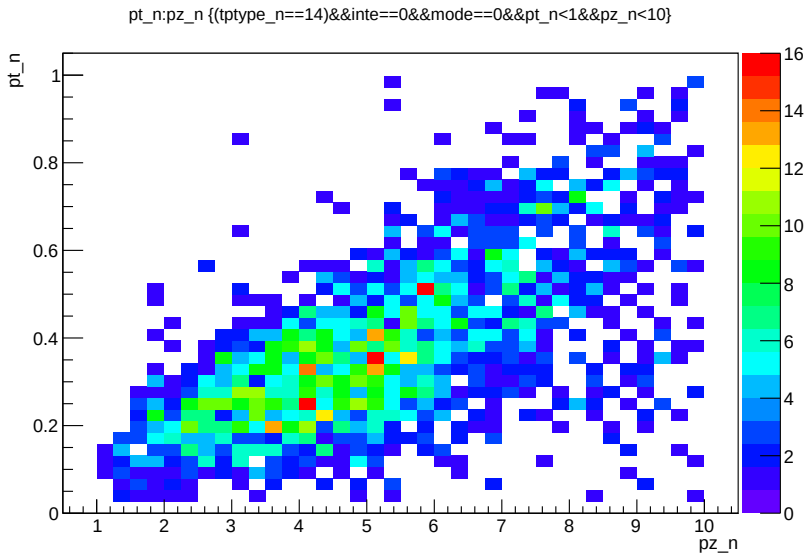
$K^- \to \bar{\nu}_\mu + \pi^0 + \mu^-$

$K^- \to \bar{\nu}_e + \pi^0 + e^-$

$\pi^{\pm}$ Weights



(a) π^{+} weights



(b) π^{-} weights

NA49 $\pi^{\pm}$ phase space coverage

The region in green is the region plotted in the previous histograms.

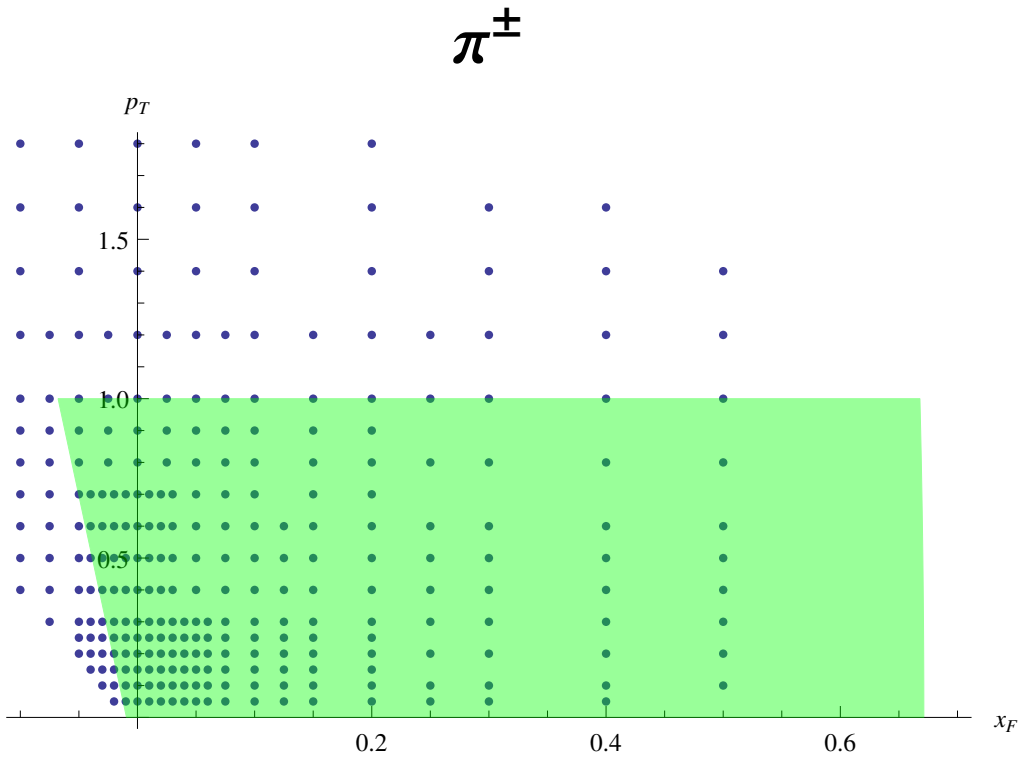
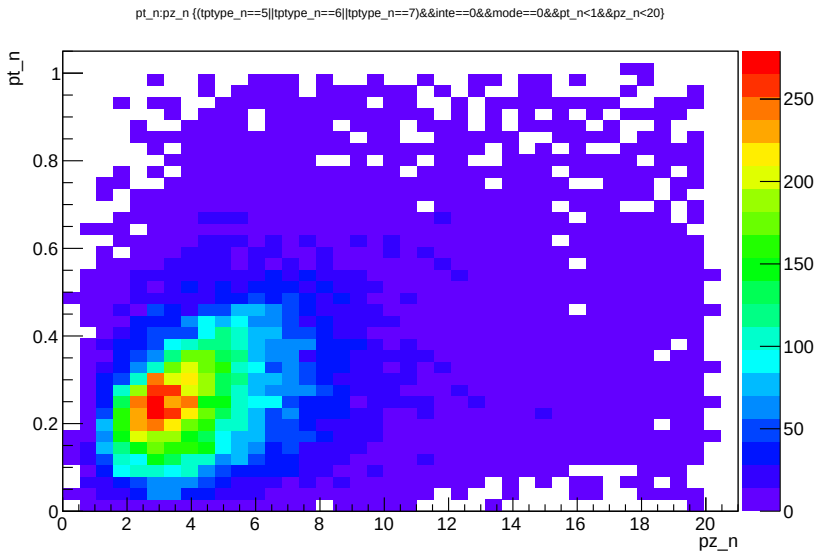
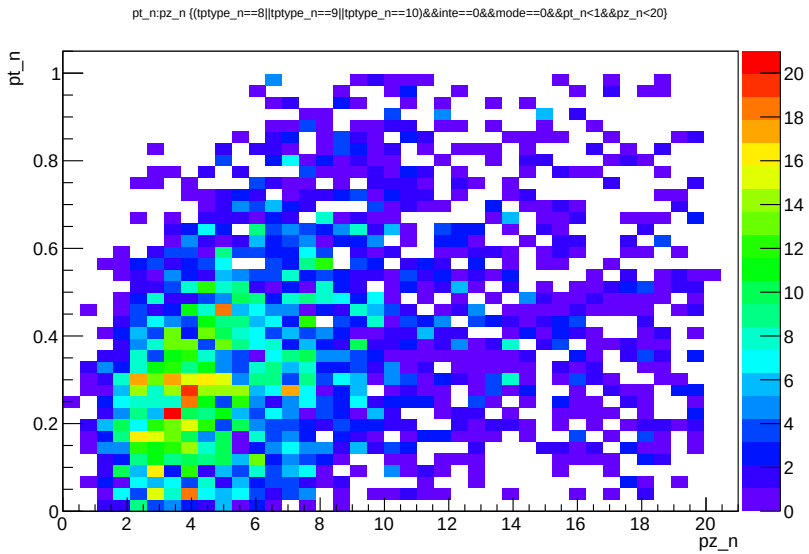


Figure: NA49 bin centers (points) and NDOS-relevant region (green)

$K^{\pm}$ Weights



(a) K^{+} weights



(b) K^{-} weights

NA49 $K^{\pm}$ phase space coverage

The region in green is the region plotted in the previous histograms.

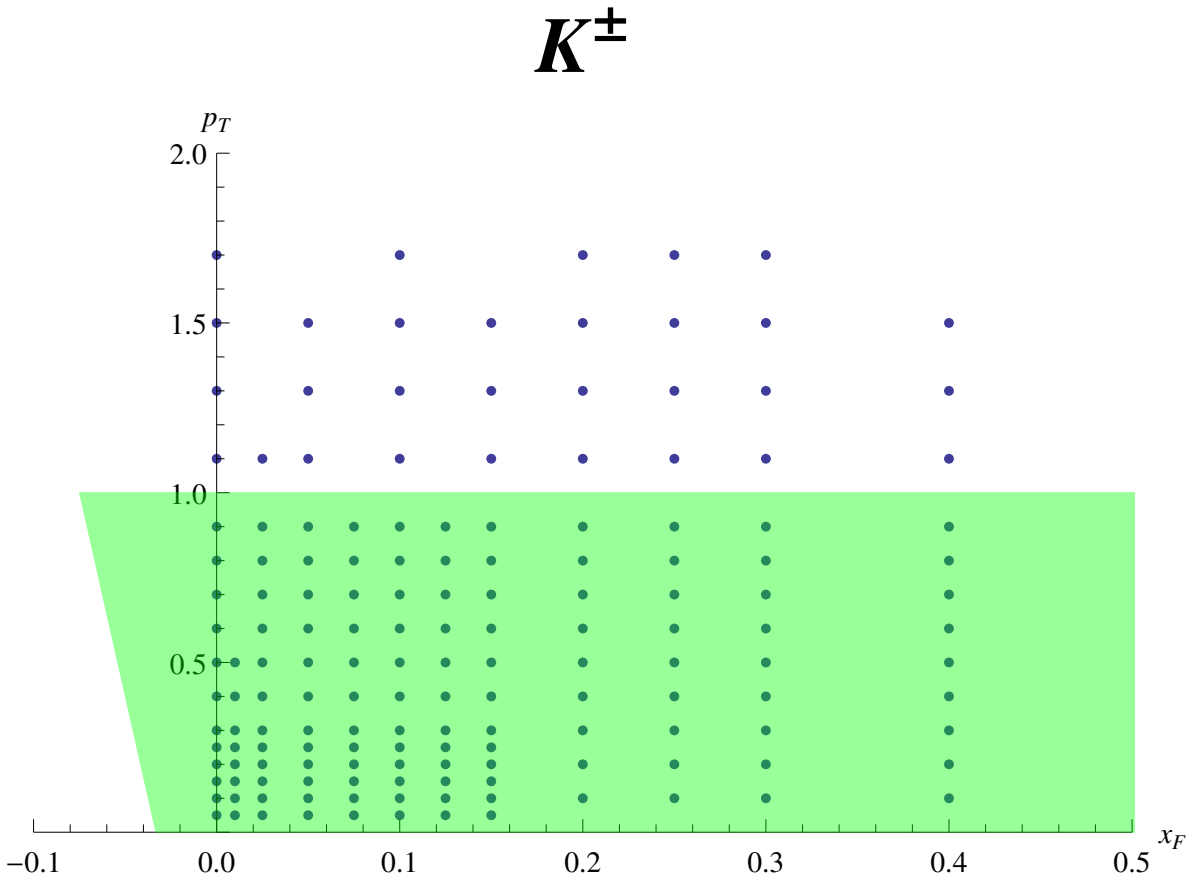
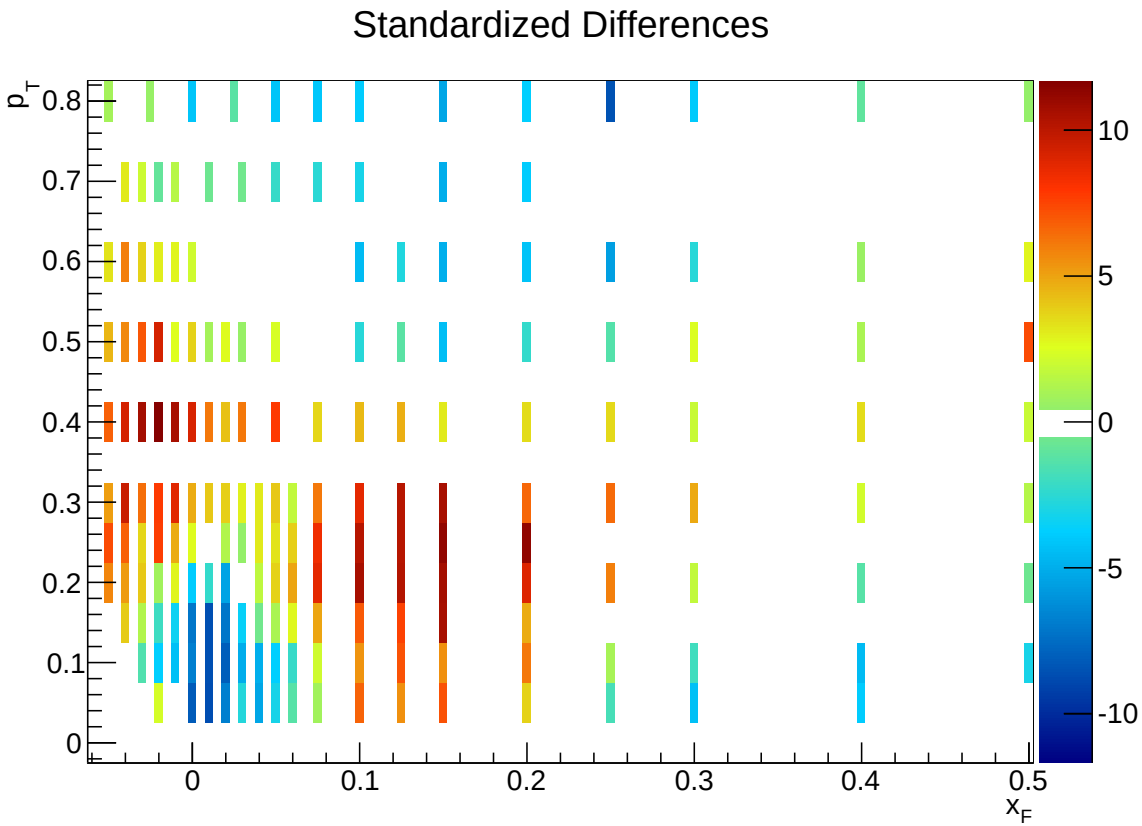


Figure: NA49 bin centers (points) and NDOS-relevant region (green)

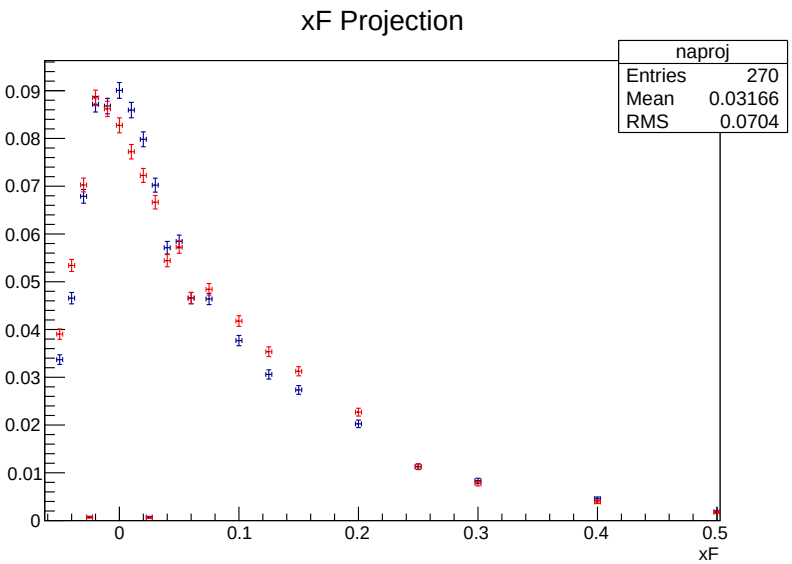
Results

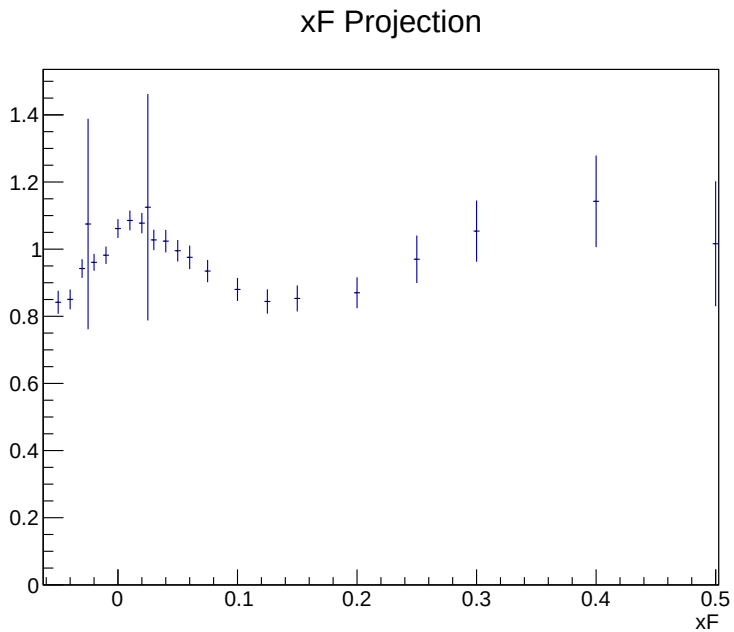
For each type of particle, we have produced difference histograms like this...
(In this example, π^+ as measured by NA49 compared with FLUKA+PEANUT, with differences measured in σ)



Results

... And from those we can create new histograms by projecting the x_F or p_T axes.
(Left: Distribution of π^+ as measured by NA49 and estimated by FLUKA. Right: Data/MC ratio of histograms in the left)



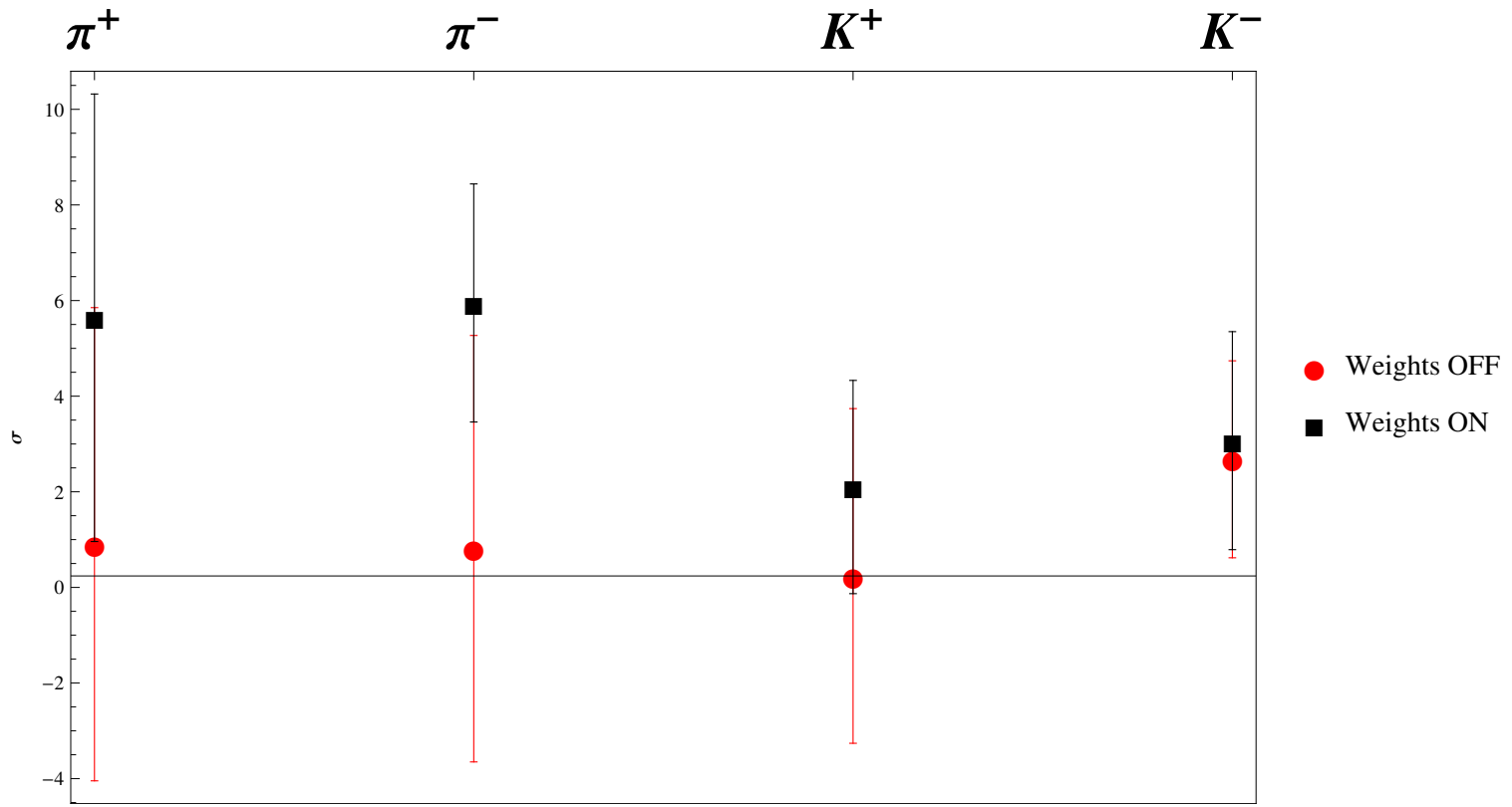


Results

Note: For simplicity, we only show results of the comparison of NA49/NA61 with FLUKA using PEANUT. As a summary, we show just the mean and standard deviation of the differences measured in σ or %, computed with and without weights. For the complete results please refer to the files mentioned in slide 23.

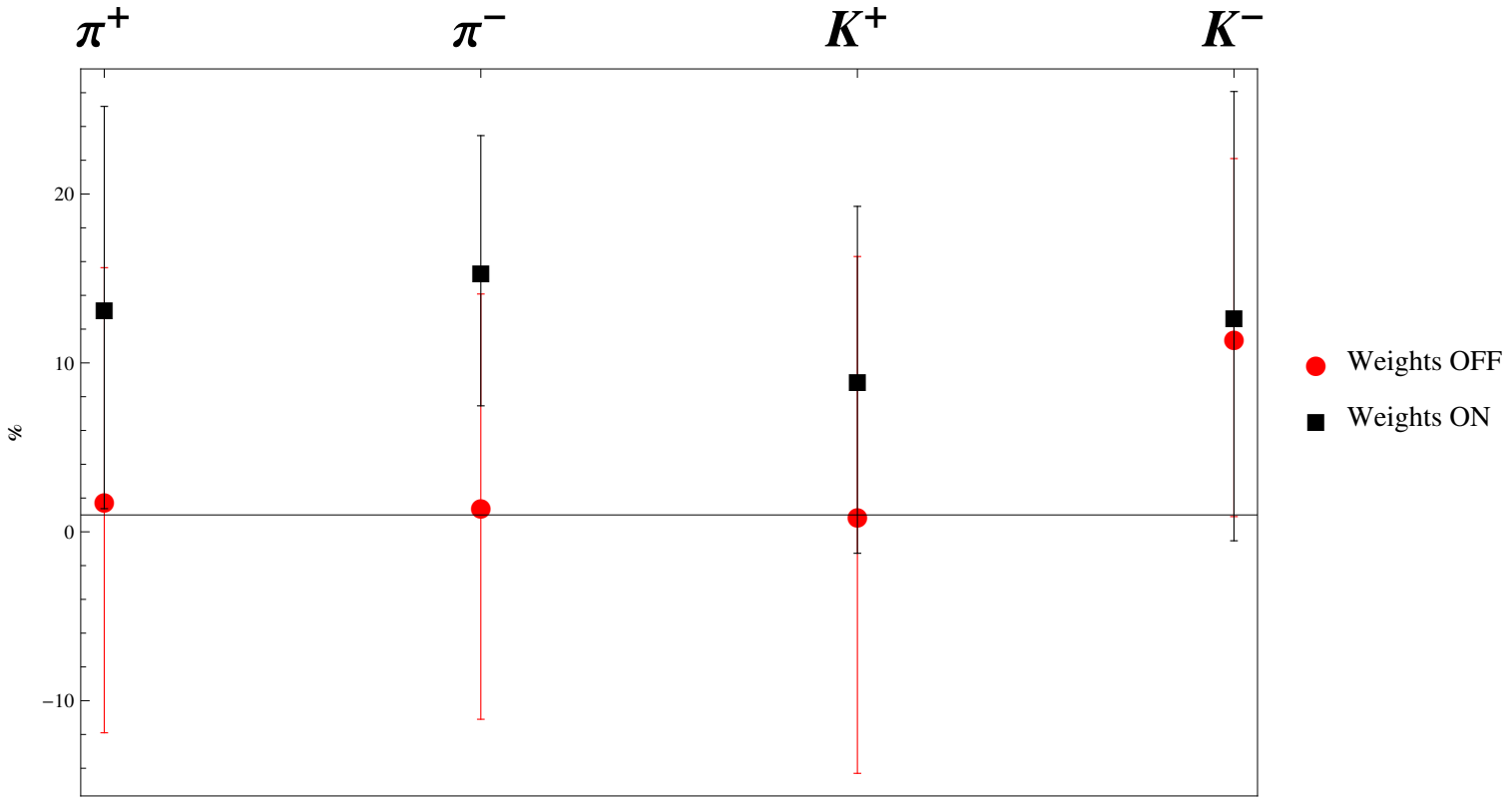
NA49 summary

FLUKA - NA49, Standardized differences



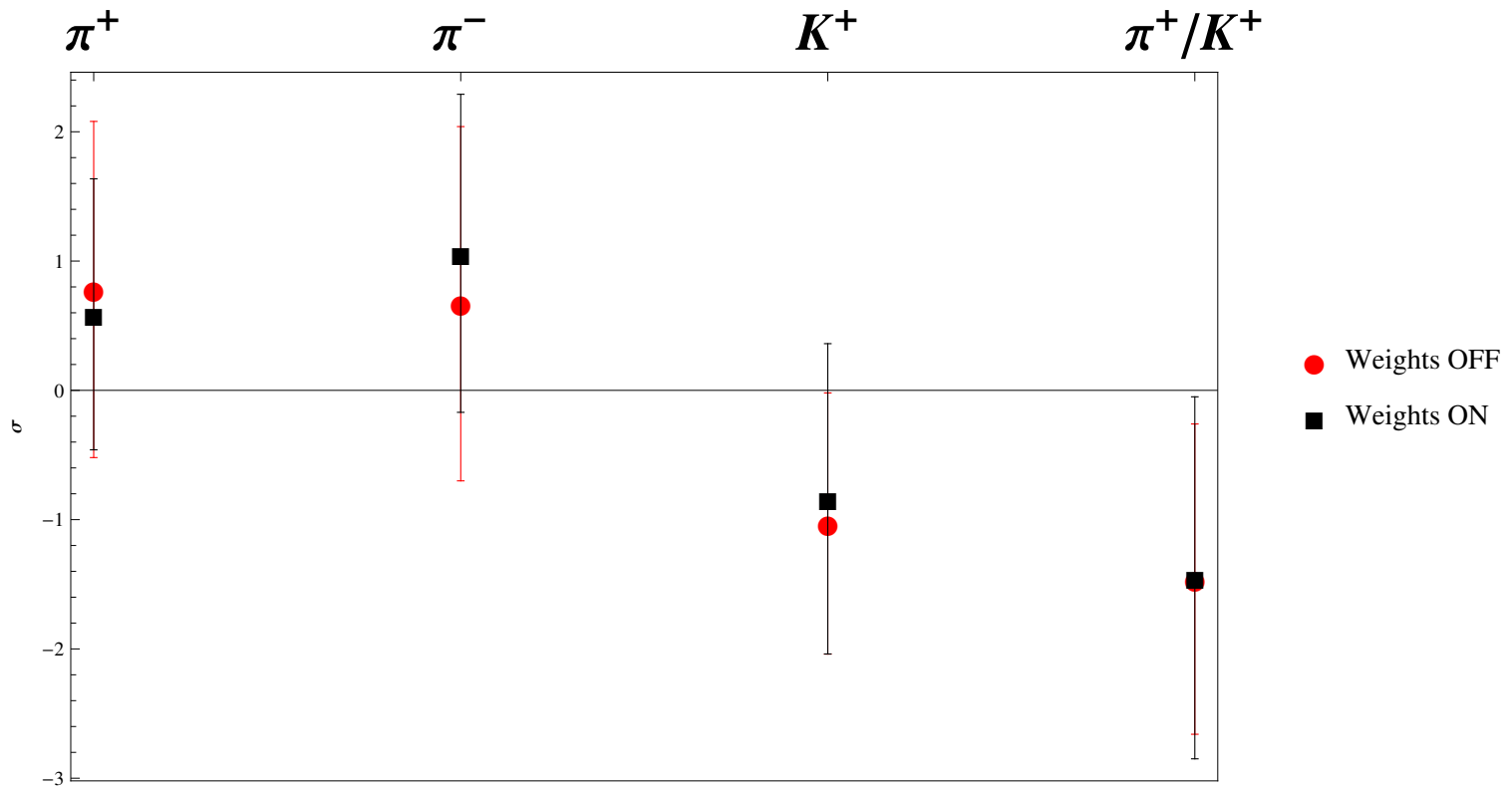
NA49 summary

FLUKA - NA49, Relative differences



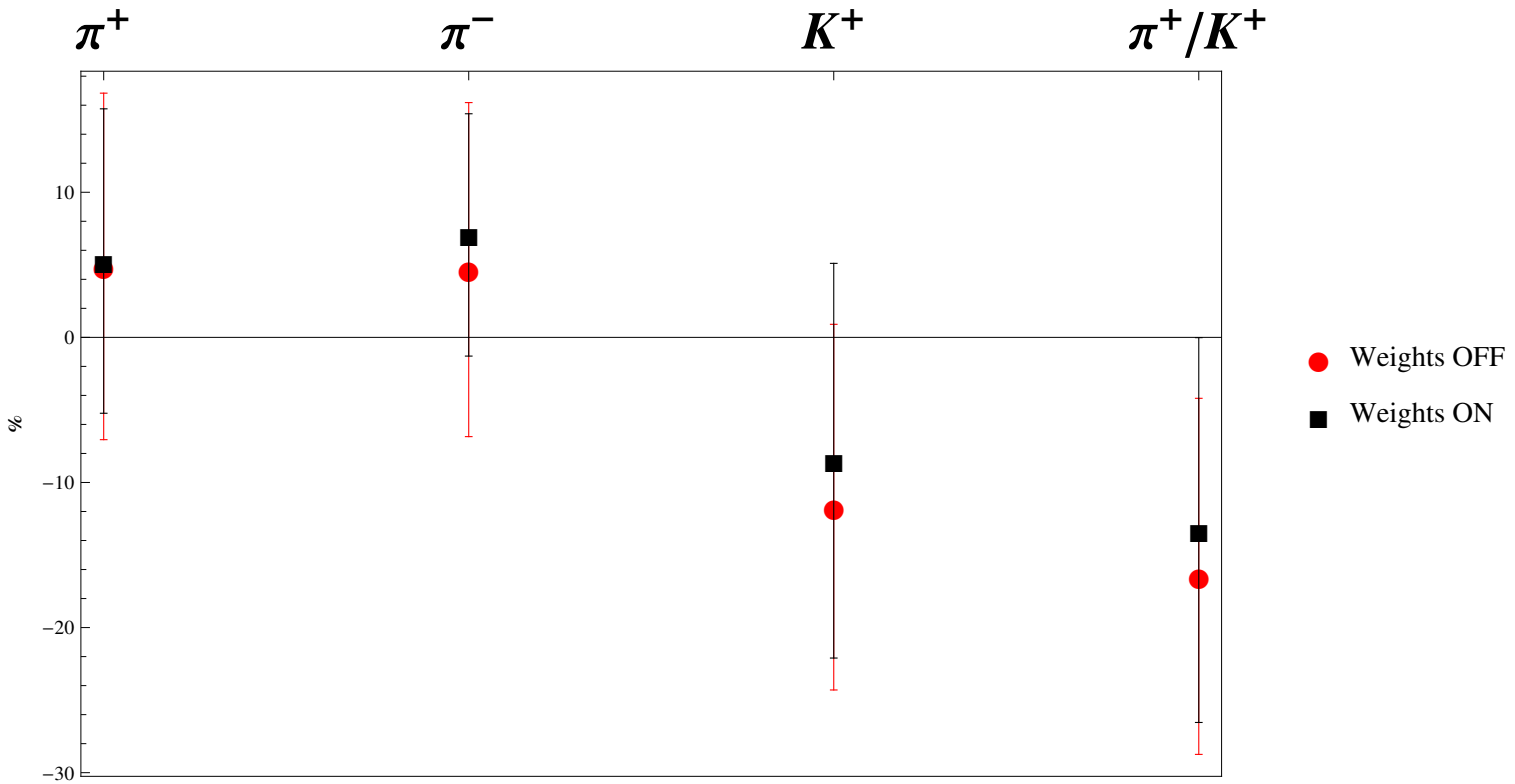
NA61 summary

FLUKA - NA61, Standardized differences



NA61 summary

FLUKA - NA61, Relative differences



Produced files

All the useful information obtained can be obtained from the files located in

`/nova/app/users/pmediano/results`

I have included results from NA49/NA61, FLUKA with PEANUT and FLUKA without PEANUT. More information in

`/nova/app/users/pmediano/results/README.txt`